(37B).   Since then I have been in correspondence with Professor A. S. Donner, Director of the University Observatory, Helsingfors, who has kindly placed at my disposal the places of nine B.D. stars from the *Astrographic Catalogue*. The star-places are contained in a volume of the Helsingfors Astrographic Zone, which is at present passing through the press. They correspond to the epoch 1896·0.

The accompanying table exhibits in parallel columns the values of $\mu_\alpha \cos \delta$ and μ_δ deduced from the catalogues and from the single Oxford plate. In the last column are given references to the catalogues compared.

Comparison of Proper Motions deduced from Catalogues with Corresponding Quantities deduced from the Oxford Plate 37B.

| No. in Table II. | $\mu_\alpha \cos \delta$ | | μ_δ | | Relative Weights of Cat. P.Ms. | Catalogues compared. |
	Catal.	Radcliffe Photo.	Catal.	Radcliffe Photo.		
12	+0″·01	−0″·01::	−0″·02	0″·00::	10	Lal.*, Grb., W.B.*, Rad. 45, A.G., Gr. 90, Hels.
37	− ·06	− ·07	+ ·05	+ ·07	6	W.B.*, Brus. 65, A.G., Hels.
53	− ·01	·00	− ·02	− ·02	6	W.B., Bonn VI.*, A.G., Hels.
75	− ·02	·00	·00	·00	4	W.B., A.G., Hels.
88	+ ·01	+ ·05	·00	+ ·02	4	Lal.*, W.B., A.G., Hels.
206	+ ·02	− ·02	+ ·04	+ ·01	2	Bonn VI.*, Bonn Veröff. 9*, Hels.
222	+ ·01	+ ·04:	− ·03	− ·05:	4½	Lal.*, Bonn VI., A.G., Paris, Hels.
232	− ·02	− ·01	+ ·02	+ ·01	4	Lal.*, W.B.*, Paris, A.G., Hels.
241	+ ·03	+ ·05	·00	+ ·01	2½	Lal.*, A.G., Paris, Hels.

Radcliffe Observatory, Oxford :
1913 *June* 24.

The Spectra of Novæ and the Pressure Effect.
Professor W. G. Duffield, D.Sc.

The spectra of temporary stars have been discussed on former occasions † with special reference to the part played by the pressure of the atmosphere surrounding a Nova, but as the investigation of sources of light subjected to high pressure has been considerably extended in recent years, a revision of the subject may be now, I think, undertaken with profit, especially as observations of the spectra of Novæ are rapidly accumulating.

* Single observations.
† Wilsing, *Astrophysical Journal*, x. 113, 1899 ; Lockyer, *Astrophysical Journal*, xv. 190, 1902 ; Hale and Kent, *Publications of the Yerkes Observatory*, vol. iii. pt. ii., 1907.

In the following examination will be found the point of view of the worker in the physical laboratory, the measurements of others upon the spectra of Novæ being necessarily taken without criticism. The treatment of the subject is designed to be of value in the future even if the data upon which I have based my present arguments should prove to be erroneous; this is why I have dwelt at some length upon the qualitative agreement between a certain aspect of the spectrum of a Nova and that of a source under pressure, though I subsequently show that existing quantitative evidence is against it. For the same reason I have been anxious throughout to bring forward more or less categorically the arguments for and against the various phenomena common to the two spectra being causally related.

At the end of the paper I have set down those conditions which, in my opinion, must be fulfilled by a system giving a spectrum of the type under consideration.

The subject is dealt with under the following headings :—

1. The doubling of the lines.
2. The broadening of the lines.
3. The intensity curves and structure of the broadened lines.
4. The reversal and relative intensities of the lines.

1. *The Doubling of the Lines.*

The phenomenon thus referred to is the occurrence upon the more refrangible edge of many broad bright lines of a broad absorption line.

It is necessary to inquire whether the bright and dark components are produced by (*a*) the same influence, or (*b*) different influences.

Qualitative Discussion.—(*a*) If both are due to the same cause, pressure naturally suggests itself, since the phenomenon can be qualitatively reproduced, as Wilsing * showed, by a spark discharge between metal poles under water. Wilsing ascribed this phenomenon to the effect of pressure on indirect evidence that a spark produced under water is under high pressure; since then lines presenting this appearance have been shown to be readily produced in certain spark † and arc ‡ discharges in compressed air.

As the elements, chiefly hydrogen and helium, which possess this characteristic feature in the stellar spectrum, are not easily examined under pressure in the laboratory, it is necessary to consider whether there is any evidence indicating that the hydrogen and helium lines are of the same general nature as those lines of other elements which are known to show doubling under pressure.

In the iron arc lines which behave thus broaden easily and suffer large displacements towards the red with increase of pres-

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* Wilsing, *loc. cit.*
† Hale and Kent, *loc. cit.*
‡ Duffield, *Phil. Trans. Roy. Soc.*, ccviii. 111, 1908.

sure; the reversal is not necessarily apparent at atmospheric pressure, the absorption line developing as the pressure is increased, but at higher pressures usually becoming less marked.   As in the spectra of Novæ the reversed part varies considerably in width on different occasions, being sometimes narrow in comparison with the bright line upon which it is superposed and sometimes nearly half its width.   Such lines all belong to what I have called Group III., these being displaced twice as much as the lines of Group II. and four times as much as those of Group I.   It has not been determined to what recognised spectrum series (if any) such lines belong, but it is to be noted that in the case of elements possessing lines belonging to a recognised series such lines are characterised by larger displacements than the non-series lines.*   There is thus some reason for regarding the lines in the iron spectrum which behave in this way as corresponding to one of the recognised series.   This cannot be pressed far, but it suggests that it is not unreasonable to look for a similar behaviour in the series lines of hydrogen and helium which occur in the spectra of temporary stars.

It is important to note that A. S. King,† who employed an electric furnace for the production of spectra under pressure, did not observe any lines to be unsymmetrically reversed when the furnace was evenly heated, although the strongest of all such lines that have been observed in the arc occur in the region of the spectrum which he examined.   This difference between arc and furnace spectra is due, I think, to the fact that in the former there is a gradient of pressure, density, or temperature in the luminous vapour, whereas in King's experiment the vapour should be nearly homogeneous.   A later experiment of King's ‡ tends to support this view, because he finds that by heating the middle of the carbon tube to a temperature higher than that of the ends a symmetrical reversal may be converted into one that is unsymmetrical.   If the pressure effect proves to be capable of explaining the doubling of the lines in a typical Nova spectrum, we have evidence that the source is not homogeneous like the vapour in King's original experiments, but that its density gradient and temperature gradient more closely resemble those of the arc; conditions which might also be realised in an advancing shell or sphere of luminous vapour in which the density of the foremost portion is less than that of the main mass.

Quantitative Discussion.—We have hitherto been concerned only with relative values of the displacement of bright and dark lines, and the phenomenon has been found to resemble closely that obtained by subjecting certain sources of light to pressure, but it was long ago pointed out that if the absolute values of the displacement in a Nova's spectrum be taken into account, the bright component will be usually found to be displaced towards the red,

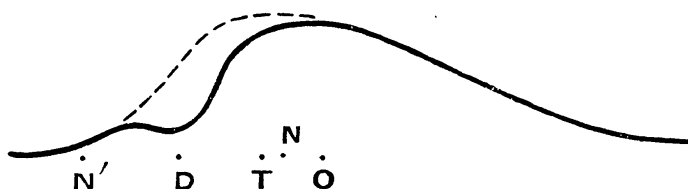* Duffield, *Phil. Trans. Roy. Soc.*, ccix. 205, 1908.
† King, *Astrophysical Journal*, xxxv. 183, 1912.
‡ King, *ibid.*, xxxvii. 119, 1913.

whereas the dark component is invariably displaced towards the more refrangible end of the spectrum relatively to its normal position. This is contrary to the usual direction of displacement due to increased pressure, and far greater in amount than can be accounted for by any possible reduction of pressure, if, as it appears, a linear relation holds down to the lowest pressures.* This is a serious difficulty in the pressure interpretation of the spectrum, and I do not think that the fact that an increase in pressure displaces some lines towards the violet assists matters much ; in the rare instances in which such lines are reversed, the absorption line, as would be expected, is less displaced to the violet than the bright part, thus providing the converse of this particular feature of the Nova.

Combination of Radial Velocity and Pressure.—On the basis of our existing knowledge of displacements towards the violet under the influence of pressure, it is impossible to refer the phenomena to pressure alone. It is, however, important to inquire whether the combination of a large radial velocity with a high pressure might not reproduce this particular feature of the observed spectrum.

I have shown elsewhere † that when unsymmetrically reversed lines are produced by pressure the reversed part is displaced approximately half as much towards the red as is the bright line when unaffected by reversal; that is to say, it is not the most intense part of the bright line which is subjected to absorption. The intensity curve of a line affected by pressure has the form represented by the full line :—

The dotted line represents the intensity curve of the broadened and displaced line when there is no absorbing vapour.

N' is the normal position of the line.

D is the position of the dark reversal.

T is the true maximum of the bright line if unaffected by reversal.

O is the observed maximum of the bright line.

This diagram may be regarded as representing the effect of radial velocity upon a line also affected by pressure, if it be supposed that N is the position of the comparison line at atmospheric pressure, and that N' is the position of the line displaced to the violet by motion, but unaffected by pressure. Qualitatively the diagram illustrates the intensity curve of the typical line in a Nova's spectrum.

* Mohler, *Astrophysical Journal*, iv. 175, 1896.
† Duffield, *Phil. Trans. Roy. Soc.*, ccviii. 111, 1908.

In this diagram NN′ = Displacement due to motion ;
ND = Measured displacement of dark line ;
NO = Measured displacement of bright line ;
N′D = Displacement of dark line due to pressure ;
and it is evident that $N^1D = NN^1 - ND$.   .   . (1).

The obvious difficulty of reconstructing the dotted intensity curve from the observations of ND and NO points to the reversed parts as providing the best means for dealing with the question.

Pressure Displacement and Wave-Length.—Before proceeding further it is necessary to draw attention to another feature of the spectrum of a body subjected to pressure. It is well known that motion in the line of sight displaces each line by an amount which is proportional to its wave-length, and it was at first thought that the pressure displacement varied in precisely the same way and that the Doppler and pressure effects were indistinguishable in this respect ; but more recent work has shown that the pressure displacement varies with a higher power of the wave-length than the first, being at least as high as the second power and probably as high as the third, but there is difficulty in distinguishing its exact rate. This result was first established for copper * and gold † by the writer, and has been confirmed by Gale and Adams ‡ and King § for iron, and more recently by the writer for nickel. This, if confirmed for other metallic vapours and gases, provides a criterion for distinguishing between the two effects if the displacements of the lines of a single element can be obtained with sufficient accuracy. If the displacement varies as the first power of the wave-length, radial motion is suspected ; if the displacement varies with a higher power, the pressure effect is inferred.

We are now in a position to deal with equation (1) if we take from the following section page 636 the fact derived from measurements of spectrograms of Novæ, namely that the displacements of the dark lines are proportional to their wave-lengths :—Thus $ND = b\lambda$. We also know that NN′ which is due to motion can be written $NN′ = a\lambda$, and that N′D is proportional to $c\lambda^n$ where n is not very different from 2 or 3, a, b, and c being constants.

Equation (1) becomes $c\lambda^n = a\lambda - b\lambda$ which is dimensionally impossible.

Hence it is impossible for the measured displacement of the dark lines to be reproduced by the combined effect of pressure and radial motion, whatever may be the origin of the bright bands. The answer to question (a) is therefore in the negative as far as pressure is concerned, even in the most favourable case when radial motion is imagined to displace the line as a whole, and in spite of the suggestive qualitative resemblances to a pressure effect.

Since a rational solution of the equation is given by $c = 0$, we

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* Duffield, *ibid.*, ccix. 205, 1908.
† Duffield, *ibid.*, ccxi. 33, 1910.
‡ Gale and Adams, *Astrophysical Journal*, xxxv. 10, 1912.
§ King, *ibid.*, xxxv. p. 183, 1912.

see that $a = b$, and that the displacement of the dark line can be explained (as was at once apparent) by radial velocity alone.   As we shall see under the next heading that the bright band is not displaced in accordance with a radial velocity (though this factor may be concerned in the broadening of the line), we conclude that the bright and dark displacements are not produced by the same cause, whether pressure or motion in the line of sight.

The Dark Bands.—If the bright and dark components are of separate origin, we must treat of them separately.   The dark lines can be divided into two groups—those that are very broad like those occurring on the violet side of the hydrogen lines, and those that are fine like the dark H and K lines on the bright calcium band and the dark D lines on the bright sodium band.

These will be subsequently referred to as dark bands and dark lines respectively.   The former are frequently double in the case of the hydrogen and helium lines.   Their displacements in the spectrum of Nova Geminorum * are given in the following table, in which d_1 and d_2 are the measured displacements of the two dark bands.   Doubtful identifications are included in brackets. Throughout this paper all displacements are in Ångström units.

<div align="center">

TABLE I.

Dark Hydrogen Bands.

</div>

	λ.	d_1.	$\dfrac{d_1}{\lambda}$.	d_2.	$\dfrac{d_2}{\lambda}$.
H_ϵ	3970·25	− 11·2	− 28	− 19·7	− 50
H_δ	4101·85	− 11·3	− 28	− 19·3	− 47
H_γ	4340·66	− 12·3	− 28	− 20·7	− 48
H_β	4861·49	− 13·8	− 28	− 23·7	− 49
H_α	6563·04	− 17·8	− 27	...	...

<div align="center">

Dark Helium Bands.

</div>

	λ.	d_1.	$\dfrac{d_1}{\lambda}$.	d_2.	$\dfrac{d_2}{\lambda}$.
	4143·92	(− 10·5)	(− 25)	(− 20·3)	(− 49)
	4437·72	(− 8·2)	(− 19)	(− 19·1)	(− 43)
	4471·65	− 11·0	− 25	(− 19·4)	(− 43)
	4922·10	− 11·0	− 22	− 21·5	− 44
	5015·73	− 11·5	− 23	− 21·0	− 42

In the third and fifth columns are given the values of the displacements divided by the wave-length.   These are sufficiently in agreement to indicate that the displacement is proportional to the wave-length for each dark band, and it is further clear that within close limits the hydrogen and helium bands possess the same rate of displacement.

Nova Persei showed a similar relationship, as may be seen by Table II., in which Campbell and Wright's measurements † are recorded.

* Adams and Kohlschutter, *Astrophysical Journal*, xxxvi. 293, 1912.
† Campbell and Wright, *ibid.*, xiv. 269, 1901.

TABLE II.

Element.	Wave-length.	d.	$\frac{d}{\lambda}$.
Calcium K	3933·83	− 17	43
,, H	3968·63	− 16	40
Hydrogen H_δ	4102·00	− 19	46
,, H_γ	4340·53	− 19	44
,, H_β	4861·57	− 24	49
Sodium D	5896·3	− 27	46

The same observers chronicle another more accurate and complete set of displacements of the hydrogen lines in Nova Persei.

TABLE III.

Line.	Wave-length.	d.	$\frac{d}{\lambda}$.
H_ζ	3889·15	19·64	50
H_ϵ	3970·33	19·98	51
H_δ	4102·00	20·79	50
H_γ	4340·53	22·91	51
H_β	4861·57	24·5	53

Comparing the corresponding hydrogen and helium displacements in Nova Geminorum, we see evidence of a common ratio of displacement of the lines of these elements, and the same fact emerges in the spectra of hydrogen, calcium, and sodium in the spectrum of Nova Persei.

It has been shown that this cannot be due to a combination of pressure and velocity, but that it must be due to velocity alone.

Hence it appears that in these two Novæ the different elements have at any time practically the same velocities as far as their dark bands are concerned, and that when the dark bands are doubled the velocities of corresponding dark bands also agree, the two values being such that one is approximately double the other. Unfortunately the displacements of bands due to other elements are rather doubtful, but the displacements of the dark bands referred to iron and titanium * suggest that they share in the common velocity.

The measurements of the fine dark lines on the bright bands of calcium and sodium are not in good agreement with one another, but in Nova Persei they indicate velocities of the vapour to which they are due varying from + 30 to + 36 kms. per second (which reduce after correction to velocities varying from + 0·5 km. to + 6 kms. per second), and in Nova Geminorum varying from + 28·5 to + 47·4 kms. per second (which reduce to velocities varying from + 1·0 km. to + 18·0 kms. per second, the mean being about + 10 kms.).

Campbell and Wright and Adams and Kohlschutter take the velocities indicated by these fine dark lines as the radial motion

* Curtis, *Monthly Notices*, lxxii. 511, 1912.

of the star as a whole, and have corrected their tables of wave-
lengths for these velocities. It appears to me to be wise to keep
distinct for the present the different sets of velocities indicated by
the spectrum, bearing in mind that those calculated for the
broadened bands are the most important as they refer to the bulk
of the absorbing vapour.

An interesting plate was obtained by Adams and Kohlschutter
on March 30, on which each hydrogen line possessed four dark
components. The displacements of these from the normal position
are given in the following table, together with the ratios of the

values of $\frac{1}{d^2}$ referred to the most displaced component.

TABLE IV.

Values of Displacements = d.

	A.	B.	C.	D.
Hδ	(11·4)	14·3	21	24·6
Hγ	12·2	14·4	20·9	24·8
Hβ	(13·8)	15·0	23 6	28·3

Values of $\rho = \frac{1}{d^2}$.

Hδ	(4·7)	3·0	1·4	1
Hγ	4·1	3·0	1·4	1
Hβ	(4·1)	3·5	1·4	1

The values in brackets are taken from a different plate, as the
component marked A was not measured on the plate under dis-
cussion. Reference will be made later to the values of $\frac{1}{d^2}$ obtained
above

The Bright Bands.—The displacements of the bright compo-
nents of the hydrogen bands are given in the following table,
which relates to Nova Geminorum.* In the fourth and fifth
columns are given the values of displacements divided by the first
and second powers of the wave-length. It is apparent that the
agreement is greater for the constant depending upon a relation
between the displacement and the square of the wave-length, a fact
to which Adams and Kohlschutter draw attention.

TABLE V.

	λ.	d.	$\frac{d}{\lambda}$.	$\frac{d}{\lambda^2}$.
Hϵ	3970·25	+ 1·25	+ 31	+ 79
Hδ	4101·85	+ 1·35	+ 33	+ 80
Hγ	4340·66	+ 1·74	+ 40	+ 92
Hβ	4861·49	+ 1·81	+ 37	+ 77
Hα	6563·04	+ 3·79	+ 57	+ 87

* Adams and Kohlschutter, *loc. cit.*

Unfortunately this is almost the only concordant evidence that I have been able to find relating to the rate of displacement of the bright bands. In Nova Persei the measurements are very vague and irregular, and are not considered very accurate by the observers,* the limits of error being several Ångström units. The following are the displacements of the bright hydrogen bands in Nova Persei for three different dates in the year 1901 :—

<div align="center">TABLE VI.</div>

	λ	d Feb. 25.	d March 13.	d March 18.
H_ζ	3889·15	…	+7	+3
H_ϵ	3970·25	…	+4	+5
H_δ	4101·85	−8	+3	+6
H_γ	4340·66	−6	+1	+6
H_β	4861·49	−9	+1	+7

It is evident that we must rely upon the Nova Geminorum measurements which favour a displacement varying with the second power of the wave-length. It should also be noted that this rests, to a considerable extent, upon the measurement of the H_α line which the observers state was not often obtained satisfactorily upon their photographs. These results support a pressure rather than a Doppler effect, because the stellar and pressure spectra agree in requiring a displacement which varies more rapidly than the first power of the wave-length. It should be remarked that this evidence is not conclusive, because the pressure displacement seems to vary with the cube and that of the bands with the square of the wave-length; but it is not so easy to distinguish between these two rates of displacement as between variations with the first and second powers of the wave-length. Consequently, using the information at our disposal, we must regard the pressure influence as favoured.

The helium bright bands have also been measured in the spectrum of Nova Geminorum, but their displacements show little obvious regularity. Adams and Kohlschutter state that on the whole they appear to be displaced proportionally to the wave-length, but examination of their data shows that the irregularities of the displacements are such that there is little to choose between variations with the first and second powers of the wave-length. If, however, a table be constructed showing the values of $\dfrac{d}{\lambda}$ and $\dfrac{d}{\lambda^2}$ for lines of the same spectrum series, rather more regularity appears. In Table VII. these values are given under the heading indicating the series to which the lines belong :—

* Campbell and Wright, *loc. cit.*

TABLE VII.

Values of $\dfrac{d}{\lambda^2}$.

Principal Series Parhelium.	1st Sub-series Parhelium.	1st Sub-series Helium.	2nd Sub-series Parhelium.
+150	+144	(+228)	+77
	(−36)	+34	+62
	+157	+34	
	(−30)		

Values of $\dfrac{d}{\lambda}$.

Principal Series Parhelium.	1st Sub-series Parhelium.	1st Sub-series Helium.	2nd Sub-series Parhelium.
+75	+60	(+95)	+35
	(−16)	+15	+36
	+77	+17	
	(−20)		

It is possible that the greater regularity thus obtained is apparent rather than real, and I realise that stress should not be laid upon it on account of the doubt expressed by the observers about the accuracy of the readings; but it is worth pointing out with caution (that it may be considered in future) that (omitting the negative values, since these are discordant with both a pressure and a Doppler explanation, and one other value which is included in brackets) the displacements are in the ratio of 34 : 70 : 150 for $\dfrac{d}{\lambda^2}$ which is in sufficient agreement with the 1 : 2 : 4 relationship found for different groups of lines of other elements when subjected to pressure to give a bias to that influence as their origin, though the spectrum series giving those ratios are not (according to Humphreys [*]) in the order here indicated.

It must be admitted that the information afforded by the displacements of the bright bands is not so reliable as that provided by the displacements of the dark bands, since it is always possible that the former are affected by absorption, and it is a matter of great importance whether their centres or brighest parts are measured. In the event of subsequent observations indicating a linear displacement (which I do not anticipate), it would involve very different velocities for the vapour responsible for the dark and bright bands respectively.

2. *The Broadening of the Spectrum Lines.*

Rossi [†] has shown that the hydrogen lines maintain their relative widths independently of the pressure, but that the absolute value of the widths is proportional to the pressure. The measurement of the widths of the hydrogen lines in a Nova might be expected to give a measure of the pressure to which this gas is subjected, but the electrical conditions of the source have so large

[*] Humphreys, *Astrophysical Journal*, vi. 428, 1897.
[†] Rossi, *ibid.*, xxxiv. 299, 1911.

an influence upon the width of a line that this can give no reliable information upon the pressure about a Nova. Qualitatively, the broadening of the lines is not unfavourable to the pressure explanation, as it is a feature of all pressure experiments, and as it is true in general, I think, that while a dense vapour may be made to give a comparatively narrow line by appropriate excitation, a rare vapour cannot be made to emit a broadened line.

It is curious that measurements of the widths of the bright hydrogen lines in the spectrum of Nova Geminorum * give a ratio which is the reverse of that found by Rossi, the H_α line being the broadest in the Nova spectrum, and the narrowest in Rossi's terrestrial determination as the following measurements show :—

	H_δ.	H_γ.	H_β.	H_α.
Width per atmosphere . .	49·3	40·4	24·7	8·7
Width in Nova . . .	22·3	23·8	28·2	38·8

In the first case the broadening is proportional to the inverse third or fourth power, and in the latter to the first power of the wave-length. This suggests that the broadening is due to a Doppler effect, since vapour whose velocity varies over a range δv will give spectral lines whose widths are proportional to $\lambda . \delta v$. If this holds good, it demonstrates that the vapour in motion is not very dense, because if it were, the more refrangible lines would be so increased in width that the linear relationship would be masked.

3. *The Intensity Curves and Structure of the Broadened Lines.*

In the spectra of Novæ it has been remarked that the hydrogen bands are frequently of a complicated nature, consisting of alternations of bright and dark lines of irregular widths. A pronounced structure which resembles this has been observed upon the wings of certain lines produced in a silver arc when subjected to pressures of a few atmospheres.† The wings of the silver lines under pressure consist entirely of fine lines spaced very irregularly : these lines extend over twenty Ångström units under a pressure of five atmospheres, and over about five times that range under twenty atmospheres. As the pressure is further increased they ultimately fill the space between the series lines and give rise to a banded spectrum. It is not known whether hydrogen, if submitted to sufficient pressure, would show this structure, but it may be remembered that the silver lines presenting this phenomenon belong to the first subordinate series, which is the spectrum series to which the hydrogen lines are referred. As far as I am aware, pressure is the only influence capable of accounting for this phenomenon.

It is also of special interest in this discussion to note that the maximum of intensity of a bright line in the spectrum of a Nova

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* Adams and Kohlschutter, *loc. cit.*
† Duffield, *Phil. Trans. Roy. Soc.*, 211, p. 33, 1911. See Plate 1.

is nearer its more refrangible edge * than the red edge, and that this is a marked feature of the distribution of intensity in a line affected by pressure, as may be seen by reference to the dotted line in the diagram on p. 634. If the broad band were wholly due to line-of-sight motion, the brightest part would mark the maximum ordinate of the velocity-distribution curve; the maxima of different lines should then be displaced proportionally to the wave-length, which is found not to be the case.

4. *The Reversal and Relative Intensities of Lines.*

In the discussion of the pressure effect by Hale and Kent to which reference has already been made, reasons are given for rejecting Wilsing's theory. My own views upon the displacements of the lines have already been expressed in detail, but a word is due regarding two other objections which they make. Their contention is that under the high pressure, which in their opinion must exist in Novæ if it is to assist in explaining the spectrum, the spectrum should be one of absorption lines upon a continuous background; this is based upon experiments with spark discharges in air under pressure and under water, and is not upheld by experiments upon arc discharges in air under still higher pressures, the reversals often becoming less numerous at one hundred atmospheres than they are at ten or twenty atmospheres. The reversal phenomena observed by Hale and Kent are thus not an *essential* feature of a spectrum under pressure, but depend upon the nature of the discharge.

The same may be said of two other points which should be discussed in this connection; the first is the possibility that all spectra may become continuous if subjected to sufficient pressure, like the spectrum of the silver arc under two hundred atmospheres; the second is the change in the relative intensities of the lines which occurs with increasing pressure. Both these phenomena depend too much upon the nature of the electrical discharge to form criteria for testing the spectra of Novæ—the continuous spectrum, for example, changes back to the line spectrum at the instant when the arc is extinguished, and the relative intensities of the lines in King's furnace tube are different from those obtained in the arc discharge, though both may be under the same pressure. Thus none of the effects discussed under the present heading are capable in themselves of settling the question under consideration.

SUMMARY.

It has been shown that the phenomenon of doubling cannot be explained quantitatively by the effect of a dense atmosphere about the Nova, even when the star as a whole is regarded as being in motion in the line of sight, and in spite of certain qualitative agreements.

* Vogel, *Astrophysical Journal*, xiii. 17, 1901 ; Curtis, *Monthly Notices,* lxxii. 511, 1912.

When the bright components were treated separately it was found that on the whole their displacements were consistent with a pressure rather than a Doppler effect, and the further evidence that their structure and intensity curves are capable of imitation in arcs under pressure supports this conclusion.

But it has also been shown, upon the basis of Rossi's experiments, that the widths of the lines cannot be explained by pressure, and that they are conformable with line-of-sight motion over a wide range of velocities. If the same vapour is responsible for both displacement and broadening, the conditions must be such that a Doppler broadening can take place about a pressure-displaced position, which might arise from vapour under pressure being in motion in all directions. Alternatively, the displacement and broadening may be due to different vapours, one mass being subjected to pressure and the other being in motion, the appearance of the bright band being due to a superposition of the two effects. But if motion be the cause of the broadening of the lines, the evidence afforded by their structure and intensity curves must be discounted.

On the other hand, the dark components are displaced to the violet by amounts proportional to their wave-length, which indicates that they are due to line-of-sight motion; if they are double, each component obeys this law. The evidence points to the velocities of the absorbing vapours being approximately the same whatever their nature. Moreover, this common velocity is not very different in different temporary stars. Whenever in a Nova the same kind of vapour appears to possess two velocities, one of them is approximately double the other. These velocities are always large, being of the order of one five-hundredth part of the velocity of light. From the existence of a few fine dark lines with much smaller displacements towards the red, there must exist a small stratum of the vapours of calcium and sodium with smaller velocities in the opposite direction.

The conditions which must be satisfied by a Nova are thus such that the bright lines are due partly to vapour subjected to pressure, and partly to vapour (possibly the same vapour) in motion with variable velocities, and the dark lines due to vapour which is in a state of motion toward the Earth.

Of the systems which have been suggested at various times to account for the spectrum of a Nova, the following conform in certain respects with these conditions :—(*a*) One in which a dense star giving a bright line spectrum is behind a second cooler gaseous star advancing towards the Earth. The improbability of such a phenomenon repeating itself in all temporary stars will be readily conceded, and the complexity of the system of stars necessary to account for the two velocities observed in the absorbing vapour of the Nova would drive an explanation upon these lines to an absurdity.

(*b*) A system resembling that of the Sun is suggested by Deslandres,* who examined the integrated light of the Sun and found that it could be regarded as giving a bright line spectrum of

* Deslandres, *Comptes Rendus*, cliv. 1321, 1912.

calcium, the H and K lines being slightly displaced to the red and being accompanied by dark lines on their more refrangible edges. Deslandres considers the dark lines to be due to absorption produced by uprushes of vapour in the prominences, and the displaced bright lines to the descent of vapour; and suggests that this is an illustration upon a small scale of what is occurring in stars of the Nova type. This system, however, would necessitate a linear rate of displacement of the bright bands with wave-length which is contrary to the evidence. The theory is further open to the objection that the broad bright bands are by no means typical of luminous vapour in a medium where the rarity is such as must exist at so great a distance from the star that the enormous initial velocity of the vapour has been reduced to zero, unless we further suppose that the range of its velocities before and after coming to rest accounts for the observed broadening; moreover, it requires that the intensely hot rising vapour should be absorbing light, and that the descending vapour, which is cooler, should be emitting it; the converse would be expected, but as it is the temperature gradient which determines whether absorption occurs or not * a definite pronouncement is difficult. I incline to the opinion that a subsequent suggestion of Deslandres, that the spaces between the fissures which emit the prominences are under high pressure, and may be partly responsible for the displacement of the bright lines to the red, is more conformable with the spectral evidence. A dense bright-line star would supply the bright bands displaced to the red, and the top of the prominences might, as suggested above, supply the broadening, and the base of the prominences might supply the dark absorption bands displaced to the violet if the velocity of the vapour be supposed sufficiently great, though the observed regularity in the displacements of the dark bands is greater than would, I think, be expected if prominences, whose velocities are known to be extremely variable, are their cause. The doubling of the dark bands constitutes a difficulty here as it does in most theories.

(c) It is also questionable whether such large velocities could exist without the vapour being projected beyond the gravitational influence of the star (this depends upon the total mass of the star), in which case it has been suggested that it would travel outwards as a shell or sphere of advancing gas. It is true that such shells might provide the absorption that is observed, but the difficulty here lies in explaining why the velocities of all elements of which we have knowledge are the same. On the simplest assumption these velocities should be determined by the rates of diffusion of the gases. They should thus be proportional to $\left(\dfrac{T}{\rho}\right)^{\frac{1}{2}}$, where T is the absolute temperature and ρ the molecular density. The necessary condition for equality of velocities is that $T \propto \rho$, which might be effected if the high

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* Schuster, *Astrophysical Journal*, xxi. p. 1, 1905.

temperature is produced by the conversion of a common transla-
tional velocity into molecular agitation, a class of phenomenon
of which that suggested by Bickerton might be a special case.
Alternatively the elements may have a common temperature and
be thoroughly mixed before being subjected to projection, but it
is unlikely that this common velocity would be maintained beyond
a certain point at which diffusion velocities would be superposed
upon it.   The two or more values of the dark absorption bands
again constitute a difficulty ; it might be expected that the foremost
part of the advancing shell would be sufficiently bright to give a
displaced line in the centre of the reversed part, but Adams and
Kohlschutter give reasons for believing that a new component is
formed on the violet side of the previously existing dark band,
which indicates another absorbing mass with a different velocity.
On the diffusion theory this must be due to either a different
temperature or different atomic aggregation.   If the latter be
conceived as possible, the molecular density is given by $\frac{1}{d^2}$.   This
is shown to possess values bearing the approximate ratios
$1 : 1\cdot4 : 3 : 4$ on a certain photograph.   Whether these are for-
tuitous future observation must decide, but there is an unexpected
approximation to an integral relationship which could not easily
be explained by eruptive prominences.   The fine dark lines appear
to be associated with the central body and to represent quiescent
absorbing vapour, their displacements representing the velocity of
that body as has already been suggested.

Hence, of the proposed systems we see that a bright-line star of
moderate density might account for bright bands displaced to the
red, and that the absorption bands might be due to gigantic uprushes
of vapour with enormous velocities either resembling those in the
Sun in which the projected material returns to the photosphere,
or possibly giving rise to expanding spherical shells of absorbing
vapour.   Both might conceivably exist simultaneously ; the latter
seems in accordance with the photographs of the subsequent
nebulosity about a Nova, the motion of the projected vapour in
the former seems capable of explaining the broadening of the bright
bands.   Such a system seems able to supply the essential features
of a Nova's spectrum as far as pressure is concerned.   It labours
under the difficulty of accounting for the huge velocity of the
vapour, which, if due to diffusion, would indicate a temperature of
almost inconceivable magnitude, but it may be that the vapours are
ionised, in which case electrical forces may partly account for the
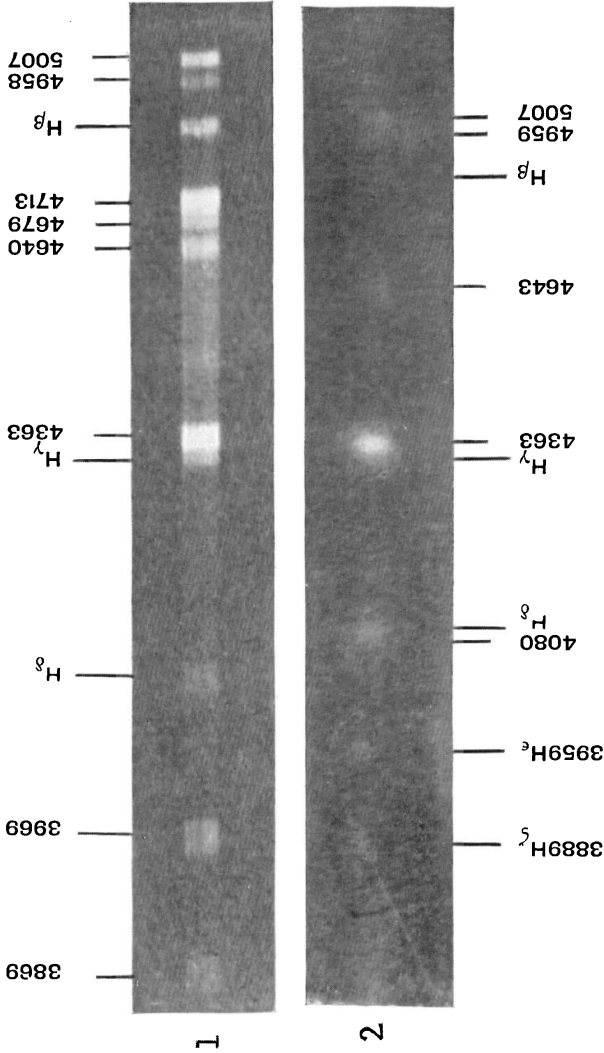high velocities.

In conclusion, it may be remarked that the displacements of the
nebular lines in a Nova's spectrum, which apparently carry on the
traditions of the hydrogen vapour, are not in accordance with the
propagation of a luminosity through a pre-existing nebula.

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The Spectrum of Nova Geminorum 2, 1912 April and 1913 February–April. By the Rev. A. L. Cortie, S.J. (Plate 21.)

Seven plates of the spectrum of Nova Geminorum 2 were secured with the Hilger single compound prism attached to the 15-inch Perry memorial equatorial in 1912 on the dates March 28, April 1, 4, 10, 11, 23, 24. At the beginning of the present year the 6-inch Dallmeyer portrait lens, presented some years since to the observatory by Mr. E. T. Whitelow, F.R.A.S., was furnished, through the generosity of the same donor, with a 6-inch objective prism of 19° angle which was made especially for the purpose by Mr. T. Thorp, F.R.A.S. The camera is attached to the tube of the 15-inch equatorial, which is used as a guiding telescope when faint objects are being photographed. The prism does full justice to the skill of its maker, and experimental exposures made on brighter stars gave a spectrum in excellent definition on every part of a quarter plate from H_α to H_η. A spectrum of the hydrogen series of α Lyræ has been utilised for the construction of a wave-length curve for the instrument. Six photographs of the spectrum of the Nova have been obtained on 1913 February 27, March 7, 11, 24, and April 4, 5. The best of these photographs is that of March 11, taken with an exposure of two hours on an Edwards isochromatic plate.

From Dr. Rambaut's measures the mean magnitude of the Nova for the series of plates in 1912 was 6·5, varying from 6·2 on March 28 to 6·8 on April 24. Mr. C. F. Butterworth has kindly furnished me with estimated magnitudes for the period nearly covering the second set of observations. The mean magnitude of the star was 8·8 and only varied 0·4 magnitude. All the measures on the plates were made on a Hilger measuring machine by myself. Of the 1912 spectra, that selected for measurement was the plate of April 24, of which a preliminary note has already been published (*Monthly Notices, R.A.S.,* lxxii. pp. 714, 715). At least three settings were made on each line and a mean value deduced. These measures converted into wave-lengths, and the estimated intensities of the lines on a scale 1–10, form the first and second columns of the annexed table. In the case of the 1913 photographs all the six plates were similarly measured independently, and no line was admitted into the final list that did not appear on at least two plates. Some of the lines were very faint and the settings difficult to make, but a satisfactory mean result has been obtained. The brightest band in all these plates was the nebular band 4363. The middle of this band, which extended over 20 Ångström units, was selected as the fiducial point with a wave-length 4360. This gave the reading 4341 for H_γ, which coincided with the wave-length of the more refrangible edge of the H_γ band in the 1912 photograph. The whole spectrum with the objective prism from w.l. 5100 to w.l. 3820 only covers 8 mm., but it has nevertheless

1. Spectrum of Nova Persei, 1901 Aug. 27. Mag. 6·6.
2. Spectrum of Nova Geminorum (2), 1913 March 11. Mag. 8·8.